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# DEVELOPMENT OF UNIFIED CORRECTION CYCLES

By

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**Sixth CRC On-Road Vehicle Emissions Workshop**
San Diego, California, March 18-20, 1996

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## ABSTRACT

A recent enhancement to estimating motor vehicle exhaust emissions has been the development of the Unified Cycle (UC). The UC is currently being used to adjust the LA4 as part of the calculation for base emission rates in California's Emission Factor (EMFAC) model. The California Air Resources Board (CARB) believes that the UC will ultimately replace the LA4 driving cycle as the base driving cycle for inventory purposes. One limitation, however, is that the UC is based on driving characteristics that occurred during the 1992 calendar year. Therefore, as driving behavior changes, the base UC emission rates will need to be corrected to reflect that change. Within the EMFAC model, speed correction factors are applied to account for these changes. As part of an on-going effort to improve the characterization of driving patterns, the Mobile Source Division of the CARB is evaluating new speed correction cycles to replace the existing cycles used in EMFAC. Several Cycles have been developed to speed correct the UC such that we can account for these changes in driving behavior. Similar to the current speed correction cycles, the new Unified Correction Cycles (UCC's) are differentiated by mean speed for a given cycle.

Eight UCC's were developed using the same database that was used to develop the UC. This database is a collection of route specific driving data that were designed to be representative of driving within the Los Angeles area. Summary statistics were developed for each route and then aggregated into mean speed bins of 15 mph to 50 mph at 5 mph increments. Trip based cycles were generated from the summary using a pseudo random microtrip selection process.

An exhaust emissions testing program, which began August 23, 1995 and will continue through March, 1996, has been developed to measure the effects of these cycles on a

vehicle's emissions and compare them with previous speed correction methodologies. A preliminary analysis has shown that the UCC's may have a similar effect on a vehicle's emissions as contrasted to current speed correction factors.

## INTRODUCTION

In 1990 the CARB set out to evaluate the representativeness of the LA4 driving cycle for estimating the current emission inventory. The LA4 is the base cycle used in the Federal Test Procedure (FTP). A study was designed to evaluate current driving patterns in the South Coast Air Basin (SCAB) by monitoring vehicle activity from a set origin and destination. Results of the study showed that the LA4 driving cycle does not represent current driving patterns, especially high acceleration and high speed events. The LA4 or FTP driving cycle was develop approximately in 1973 and the original cycle had to be modified to limit the acceleration rates to 3.3 mph/s due to dynamometer capabilities [1]. As a result the UC was developed to improve the representativeness of modern day driving. A comparison of the UC, LA4, and the LA92 database has previously been made and the results have shown that the UC is a better representation of contemporary driving, and therefore better simulates a vehicle's exhaust emission rates [2, 3]. Unfortunately, the UC may only be representative of driving in the 1992 calendar year and the SCAB. As driving behaviors change the cycle may need to be changed/adjusted to correct for the difference in driving behavior.

This has led to the reevaluation of the current Speed Correction Factors (SCF's) used in EMFAC. Currently, EMFAC uses 12 different cycles to represent non-FTP running exhaust emissions. The cycles have a mean speed range from 2.5 mph to 65 mph. Many of these cycles were developed for purposes other than using them as speed correction cycles, therefore they may not be truly representative of driving in this range. Like the FTP, almost all of the speed correction cycles have accelerations limited to less than 3.3 mph/s.

The UCC's were developed to represent a broad range of mean speed driving and also be representative of real world driving. The LA92 database was used to develop the UCC's because it was designed to be representative of trip based driving in the Los Angeles area[3]. Prior to developing any cycles, each route/trip was binned into its respective mean speed bin. Analysis of the data has shown that there is a substantial difference in driving on a per trip basis. Each bin was subsequently analyzed for several variables including mean speed, speed-acceleration frequency distribution, positive kinetic energy (PKE), load, maximum acceleration, maximum deceleration, percent idle, percent acceleration, distance, etc. Strict definitions were used to define the frequency of driving for idle and cruise. Percent idle was defined as zero speed and zero acceleration, whereas percent cruise was defined as speed greater than zero and acceleration equal to zero. As can be seen by Figure 1, several patterns are prevalent with a change in mean speed.

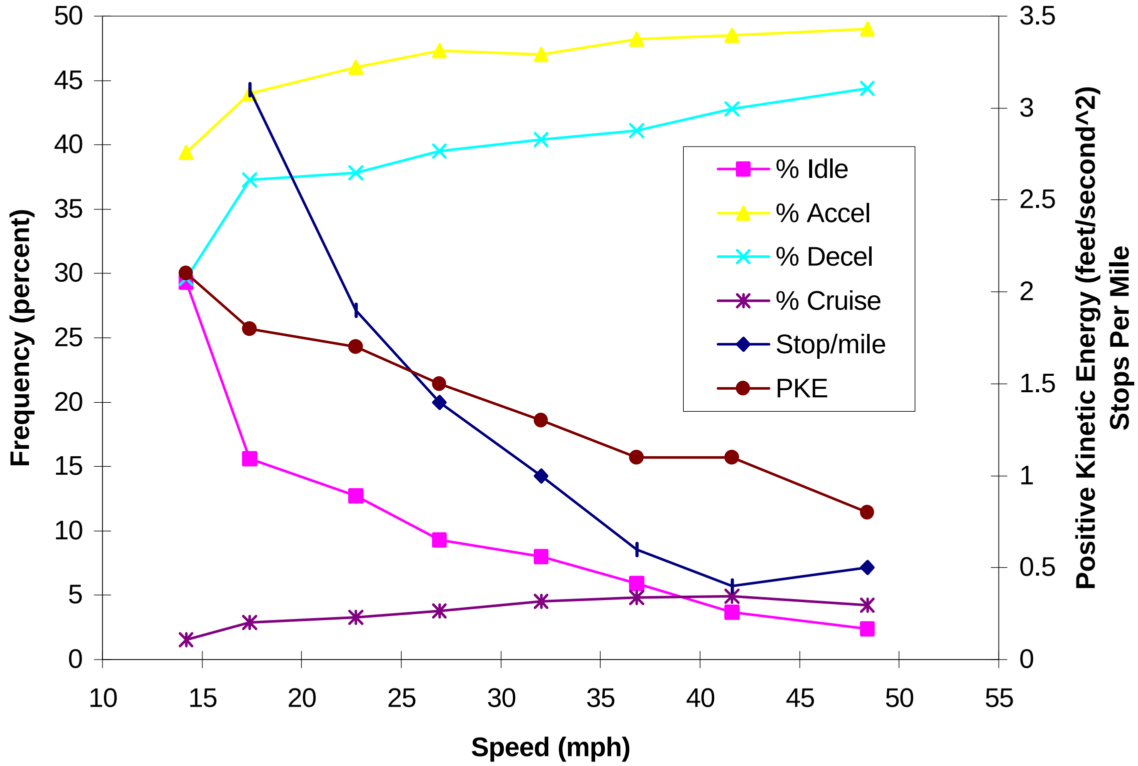


Figure 1 . Comparison of driving characteristic for each route mean speed bin.

In addition to the trends noted above, each mean speed bin was analyzed for its speed-acceleration frequency distribution. As shown in Figure 2, similar trends can be noticed for the frequency distribution. The low speed bin tends to have a higher frequency of driving at low speed and acceleration whereas the high speed bin tends to have most of the driving occur at the opposite end of the spectrum. Only three of the frequency distributions are shown in Figure 2 to illustrate the trend. The frequency distributions for the 20, 25, 35, and 40 mph bins have also been reviewed. In reviewing all eight mean speed bins, a gradual transition in frequency distribution from one bin to the next was observed, even though Figure 2 gives the appearance of a sharp change in frequency distribution between the 15, 30 and 45 mph mean speed bins.

## DISCUSSION

### Review of Cycle Development Methodologies

In order to determine if these trends produce a variation in emissions, trip based driving cycles were developed such that a vehicles exhaust emissions could be measured. Over the past decades driving cycles have been developed using several different approaches including simple 5th wheel speed data collection to complex data logger collection with computer algorithms to design the cycle [3,4,5,6].

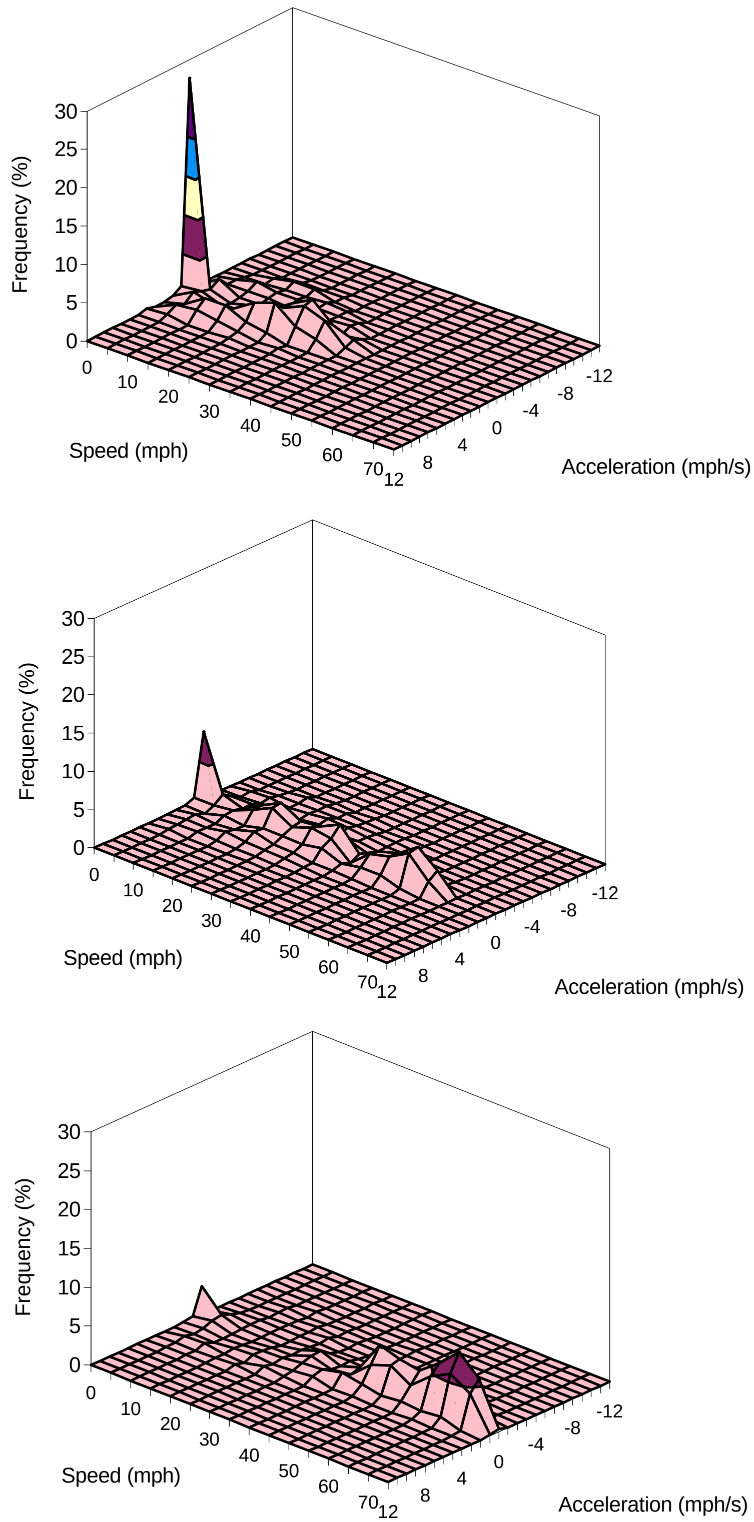


Figure 2. Speed and acceleration frequency distribution for the 15, 30 and 45 mph bins.

The cycle development approach by Effa et al. 1993 in general was to design facility specific cycles for freeways and arterials using a snippet approach. The development of facility specific driving cycles would allow for conformity analysis. A “snippet” is a change in traffic density for a given freeway or a change in the physical link of an area’s transportation network [4]. The snippets were then binned based on parameters set by the author and then several hundred cycles were developed for each bin. The best cycle was chosen from each bin based on a representativeness of two measures; closeness to the center of the bin and percent coverage. Although this methodology produced a statistically strong fit to the data, one problem is inherent to the methodology; breaking up the microtrips into snippets and then rejoining them to make microtrips tended to make abrupt changes to the speed time profile. This could potentially introduce artificial accelerations and decelerations which may be unrealistic in the real world setting. Part of the reasoning to break up the driving into individual snippet was to distinguish between links. Since the UCC project was to determine trip based cycles and not facility specific cycles a different approach was developed.

Another approach used by Crauser et al. 1989 is similar to the method above, however, individual microtrips were analyzed. The microtrips were analyzed for time of trip, distance, idle, average speed, maximum speed, frequency of stable speed, and frequency of time within a given speed range. Again, a cluster analysis was used to bin the all the microtrips prior to combining into cycles. This approach produced a cycle where each of the microtrips selected were generally alike. CARB staff is concerned that this approach would tend to miss extreme driving episodes.

**UCC Cycle Development Methodology**

As part of the development of the UCC’s it was desired to create trip based cycles which were not biased towards producing similar microtrips throughout the cycle. Since it is likely that the clustering methods described above may contribute to this feature, a somewhat different methodology was designed to combine the microtrips. A conceptual outline of the methodology used to develop the UCC’s is presented in Figure 3. Using this flow diagram a complex computer model was designed using SAS for the UNIX environment. Prior to the execution of the cycle development program several steps needed to be perform in order to execute the program. First, the mean speed was calculated for all the routes within the LA92 Database, and then each route was binned into appropriate speed bins ranging from 15 to 50 mph. Second, each bin was analyzed for several variables including mean speed, speed-acceleration frequency distribution, PKE, load, maximum acceleration, maximum deceleration, percent idle, percent acceleration, distance, etc. The summary information provided by these bins was used as the target to match the cycle. In addition, the mean trip length was used in determining cycle length. Finally, each microtrip within the LA92 database was analyzed for the driving characteristics mentioned above. The beginning of the cycle development program starts by initializing the mean speed bin for which a cycle is to be developed. Then a seed microtrip is randomly selected from one of the first microtrips in the bin.

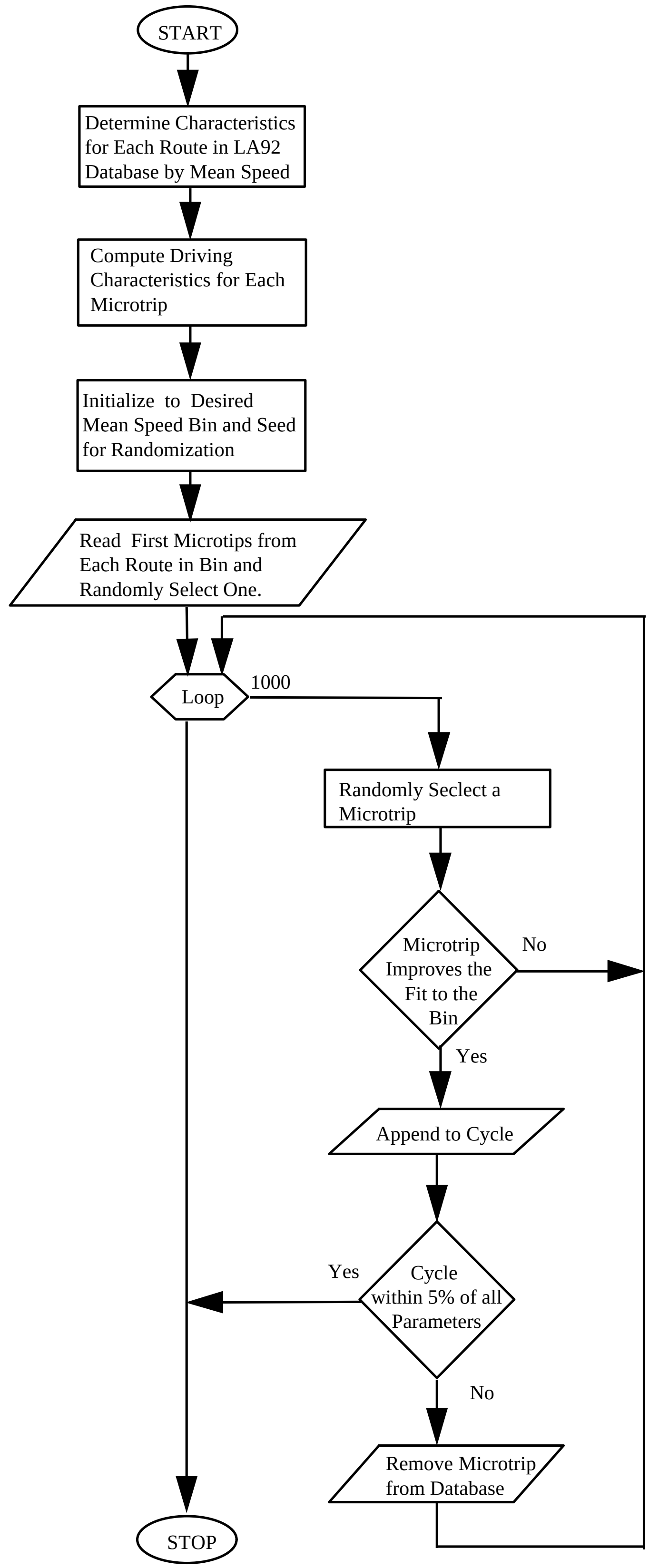


Figure 3. Flow Diagram for Cycle Development Methodology

Each bin normally had several routes from which to choose. As noted in Figure 3, the computer model goes into a loop which randomly selects microtrips, determines if the microtrip is favorable by judging a goodness of fit to the bin, appends or deletes the microtrip from the cycle, and then determines if the cycle is within 5 percent of all criteria. The program loop is executed 1000 times or until a favorable cycle is generated. While developing the computer model, it was determined through trial and error that if a developing cycle did not converge within 1000 iterations, it would more than likely not converge. Cycles were generated one at a time, and execution of the model required approximately one hour for every attemp at a cycle. If a better fit to the bin was desired after the first run, the program was re-executed with a different randomization seed. Several attempts at generating a cycle were required prior to obtaining satisfactory cycles. Seven cycle were generated using this methodology. The 50 mph bin unfortunately only had one route/trip within the bin, therefore this one trip was used as UCC 50.

Summary statistics for all of the UCC’s are presented in Table 1. As noted in the table, most of the driving characteristics for the UCC’s have a favorable match with their bin. The methodology used in developing the UCC's did not use two of the parameters in Table 1; they are percent deceleration and percent cruise. It was initially thought that these two driving characteristics would not be needed to develop the cycles for three reasons. First, these two parameters may not play an important roll in determining exhaust emissions for newer model passenger cars. Second, since percent acceleration and percent idle were already being used as parameters, either percent deceleration or percent cruise are redundant. Finally, it was determined that the more parameters that were used the more difficult it was for the cycle development program to converge on a candidate cycle. As shown in Table 1, the UCC’s have a good match for percent deceleration, but unfortunately, a poor match with the amount of cruise driving. The unfavorable match for cruise could be due to the strict definition used for cruise -- an acceleration of zero mph/s at speeds greater than zero mph.

## Test Program for the UCC's

A test program was developed to determine if the driving patterns noted above produce different exhaust emission results. Approximately 81 vehicles were tested covering a wide range of model years. A representation of the vehicle distribution by model year and fuel delivery type are shown in Table 2. The vehicles were tested in as-received condition, unless prevented due to safety concerns , then minor repairs (i.e. brakes, tires, etc.) were made to the vehicle. No special consideration was given to exhaust emissions, tampering or malmaintenance. The vehicle’s fuel tank was drained and filled with Phase I summertime fuel prior to preconditioning and testing. Prior to hot start testing, all vehicles tested on the UCC’s were preconditioned for 5 minutes at 50 mph. In addition to the eight UCC's, an FTP and UC test were performed on each vehicle. The first day of testing consisted of a FTP and then four UCC's using a predetermined randomization schedule. The second day of testing started with a UC and the remaining UCC's in random order.

Table 1. Comparison of the mean speed bins with the UCC15, UCC20, UCC25 UCC30, UCC35, UCC40, and UCC45.

| | Mean Speed | Max Speed | Max Accel | PKE | Distance | Stops/ Mile | Idle (%) | Accel (%) | Decel (%) | Cruise (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| **UCC15** | 13.34 | 36.50 | 4.60 | 2.20 | 1.56 | 3.84 | 27.72 | 40.52 | 27.49 | 4.26 |
| **Bin 15** | 14.25 | 35.00 | 4.64 | 2.13 | 1.49 | 3.76 | 29.35 | 39.45 | 29.66 | 1.54 |
| **% Diff** | 6.39 | 4.29 | 0.86 | 3.29 | 4.70 | 2.13 | 5.55 | 2.71 | 7.32 | 176.62 |
| **UCC20** | 17.72 | 43.80 | 5.70 | 1.92 | 4.12 | 3.16 | 16.15 | 42.34 | 32.78 | 8.73 |
| **Bin 20** | 17.35 | 43.04 | 5.63 | 1.85 | 3.92 | 3.11 | 15.61 | 44.13 | 37.35 | 2.90 |
| **% Diff** | 2.13 | 1.77 | 1.24 | 3.78 | 5.10 | 1.61 | 3.46 | 4.06 | 12.24 | 201.03 |
| **UCC25** | 22.97 | 49.86 | 5.89 | 1.72 | 5.44 | 2.02 | 13.25 | 43.84 | 34.11 | 8.79 |
| **Bin 25** | 22.68 | 50.23 | 5.87 | 1.72 | 5.36 | 1.94 | 12.76 | 46.17 | 37.78 | 3.30 |
| **% Diff** | 1.28 | 0.74 | 0.34 | 0.00 | 1.49 | 4.12 | 3.84 | 5.05 | 9.71 | 166.36 |
| **UCC30** | 26.89 | 59.10 | 5.48 | 1.41 | 7.35 | 1.36 | 8.84 | 45.53 | 40.04 | 5.59 |
| **Bin 30** | 26.94 | 58.70 | 5.55 | 1.48 | 7.13 | 1.39 | 9.38 | 47.34 | 39.52 | 3.76 |
| **% Diff** | 0.19 | 0.68 | 1.26 | 4.73 | 3.09 | 2.16 | 5.76 | 3.82 | 1.32 | 48.67 |
| **UCC35** | 31.96 | 68.70 | 5.62 | 1.27 | 11.98 | 1.00 | 7.92 | 45.70 | 41.18 | 5.18 |
| **Bin 35** | 31.97 | 65.88 | 5.96 | 1.30 | 11.52 | 1.00 | 8.01 | 47.00 | 40.45 | 4.53 |
| **% Diff** | 0.03 | 4.28 | 5.70 | 2.31 | 3.99 | 0.00 | 1.12 | 2.76 | 1.80 | 14.35 |
| **UCC40** | 35.60 | 72.39 | 5.51 | 1.11 | 13.18 | 0.68 | 5.63 | 47.19 | 39.23 | 7.95 |
| **Bin 40** | 36.41 | 70.88 | 5.72 | 1.14 | 12.71 | 0.66 | 5.93 | 48.19 | 41.07 | 4.81 |
| **% Diff** | 2.22 | 2.13 | 3.67 | 2.63 | 3.70 | 3.03 | 5.06 | 2.08 | 4.48 | 65.28 |
| **UCC45** | 44.64 | 71.40 | 5.70 | 1.06 | 16.17 | 0.43 | 3.76 | 45.78 | 39.34 | 11.12 |
| **Bin 45** | 41.58 | 70.49 | 6.04 | 1.08 | 16.14 | 0.42 | 3.74 | 48.54 | 42.83 | 4.88 |
| **% Diff** | 7.36 | 1.29 | 5.63 | 1.85 | 0.19 | 2.38 | 0.53 | 5.69 | 8.15 | 127.87 |
| **UCC50** | 48.44 | 76.00 | 5.66 | 0.83 | 27.43 | 0.47 | 2.40 | 2.76 | 44.38 | 4.22 |

Table 2. Fleet mix for UCC's test program by model year and technology group.

| | 77 | 78 | 81 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carb** | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 2 | 1 | 1 | | | | | | | 15 |
| **TB** | | | | 1 | | | 1 | 2 | 2 | 4 | 2 | 1 | | | | | 13 |
| **FI** | | 1 | 1 | 1 | | 1 | 5 | 5 | 6 | 6 | 5 | 3 | 4 | 10 | 2 | 3 | 53 |

## RESULTS

This project produced eight driving cycles that ranged in speed from approximately 15 to 50 miles per hour. Over the testing phase of the project several results were produce which were similar to other CARB projects which characterize driving patterns including the current speed correction factors. In general, these studies have shown that emissions are a function of mean speed.

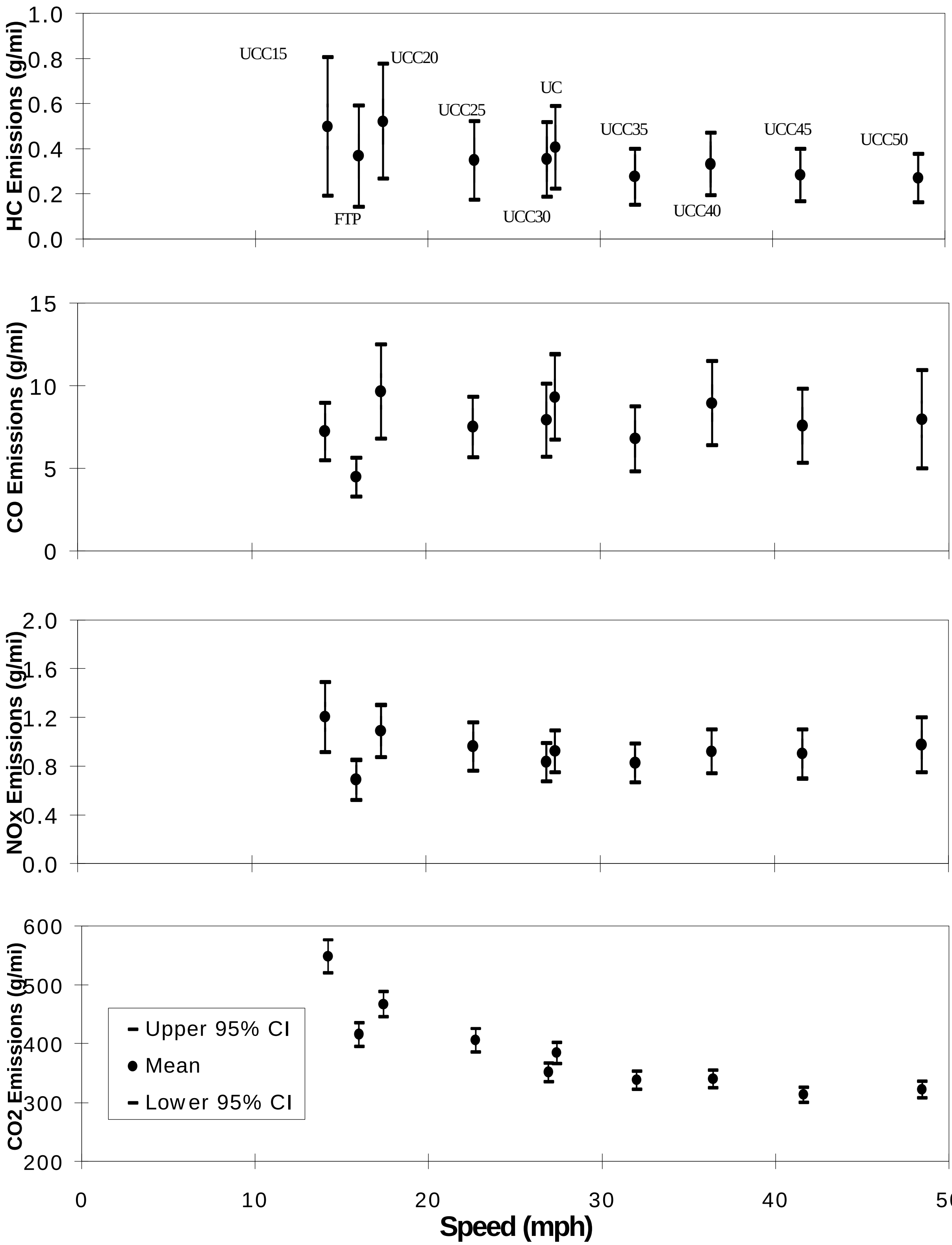


Figure 4. Mean exhaust emissions and confidence intervals for the FTP, UC, UCC15, UCC20, UCC25, UCC30, UCC35, UCC40, UCC45, and UCC50.

As shown in Figure 4, exhaust emissions do vary as a function of speed. Definite trends are apparent for HC, $NO_x$ and $CO_2$ emissions. Bag 2 exhaust emission results are presented for the FTP and UC. Please note, that if the FTP is removed from the graph, a linear trend is produced for HC exhaust emissions where a quadratic trend is produced for $NO_x$ and $CO_2$. As shown in the figure the FTP exhaust emission rates are significantly different from several of the UCC's for CO, $NO_x$ and $CO_2$ emissions. Also, the FTP does not follow the general trend produced by the UCC's. As discussed earlier, the lower exhaust emission rates for the FTP can be associated to several shortcoming from the way the cycle was developed and the change in driving patterns for modern day vehicles. The UCC15 also tends to be lower for HC and CO than what is expected. There is also a small increase in all of the exhaust emission rates for the UC compared to the UCC's. Although the UC was designed to be a self weighted cycle, its distance was arbitrarily set. The distances for the UCC's are based on the average trip length for each of the mean speed bins. This may be an explanation why there is an increase in exhaust emissions rates for the UC.

Part of this project is to determine if the UCC's can be used as future SCF's into the EMFAC model. Therefore, a simple comparison of the current SCF's in EMFAC7G was made with the UCC's. Figure 5 shows the current SCF's and the results produced using the UCC's. Note that the SCF's shown are for the SCAB during the 1995 calendar year. Due to sample size constraints the UCC's may not be fully representative of the 1995 fleet and this may partially explain some of the observed differences. The SCF from EMFAC7G are normalized to 1 at 16 mph -- the mean speed of Bag 2 of the FTP -- whereas the UCC's are normalized to 1 at 27.4 -- the mean speed of Bag 2 of the UC. The technique used to speed correct the UC was by ratioing the mean of the UCC's with that of the mean of the UC. The UCC curve does not include the FTP bag 2 exhaust emission results because the UCC's are designed to speed correct the UC. The UCC's follow a similar trend to that of the current SCF's. For HC exhaust emissions, the UCC's produce a linear trend over the range of driving. At low speed driving the current SCF's predict a large increase in exhaust emissions for the lower cycle speeds. A possible reason why the UCC's do not necessarily predict similar results may be because the lowest UCC is rated at approximately 15 mph, whereas the lowest cycle speed used for SCF's in EMFAC7G is approximately 2.5 mph. The same logic could also be applied to the higher speeds. The speed for the UCC's stop at approximately 50 mph whereas there is a 65 mph cycle used for SCF's. Since the low and high speed driving extremes are not represented by the UCC's, it cannot be determined if the UCC's will follow the same quadratic trend as the SCF's. The CO exhaust emission results produce no noticeable trend, whereas $NO_x$ and $CO_2$ follow quadratic trends. The UCC's also produce higher correction rates for CO, $NO_x$ and $CO_2$, however, a similar rate is produced for HC exhaust emissions.

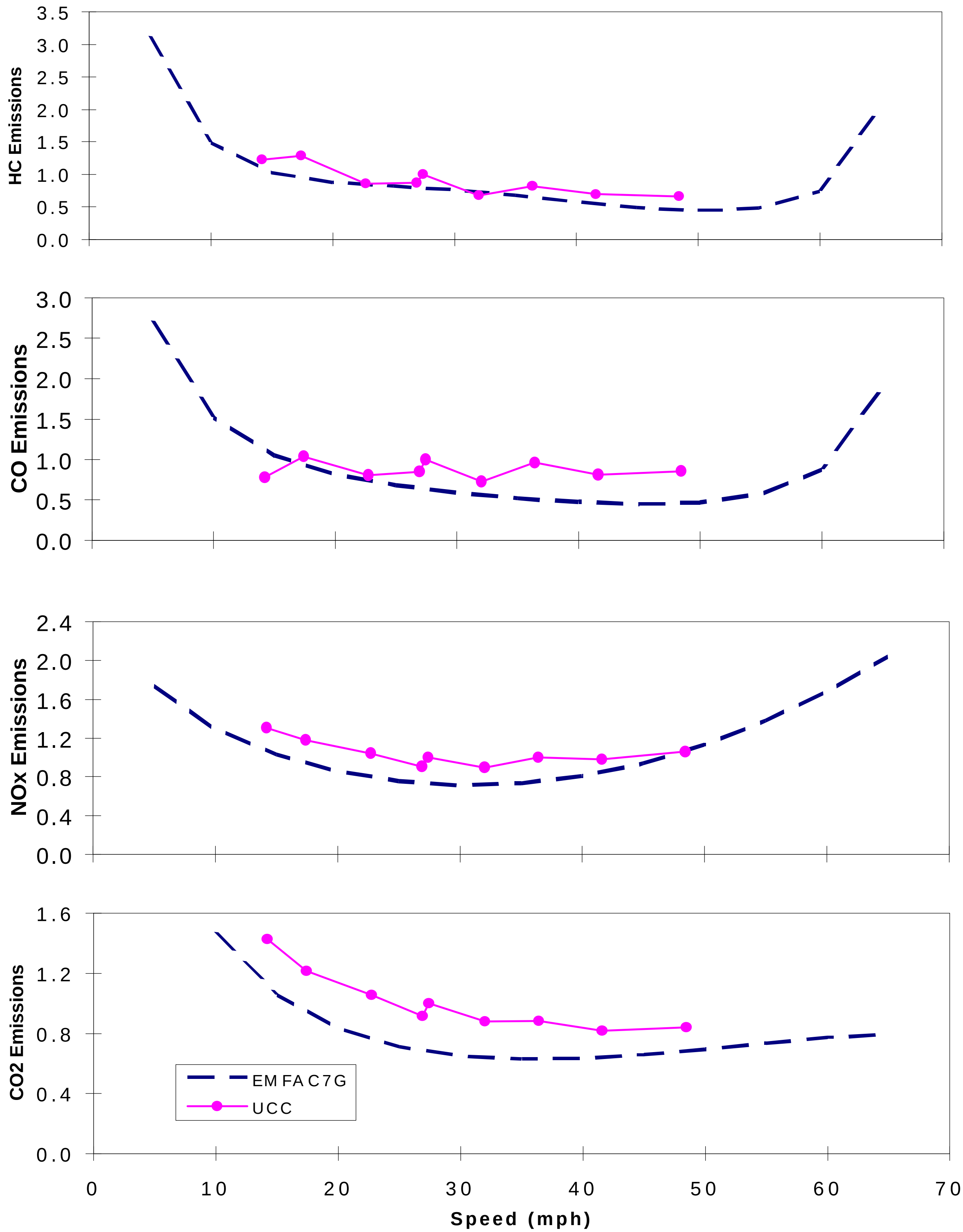


Figure 5. Comparison of Normalized UCC's with EMFAC7G Speed Correction Factors.

## CONCLUSION

This project was a first attempt at developing trip based driving cycles which can be used to represent real world driving in the 15 to 50 mph mean speed range. Eight UCC's were developed and compare favorably to the driving characteristics used as the design criteria. The UCC's produced general trends that are consistent with current SCF's. In addition, the results have shown that although there is an agreement with the trend produced by the SCF's, they do not necessarily result in an equivalent amount of correction.

## FUTURE WORK

Additional driving cycles need to be develop which represent the low and high speed driving extremes. As shown in Figure 5, there is a general agreement with the current SCF's but the full realm of driving may not be represented by the UCC's. The UCC methodology used the LA92 database, which did not contain low and high speed driving. Another effort to represent low and high speed driving will be conducted using the data collected in CARB's instrumented vehicle project.

## ACKNOWLEDGMENTS

We would like to thank the staff of the California Air Resources Board's Haagen-Smit Laboratory that performed the UCC testing program, in particular, Jose Rios, Pons Lazo, and Dennis Calgaro. Their valuable experience and knowledge as Test Engineers was essential to making the project a success.

## DISCLAIMER

The opinions, findings and conclusions expressed in this paper are those of the staff and not necessarily those of the California Air Resources Board.

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